

Power control of voice users using pricing in wireless networks

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Network Performance Group



Resource Allocation in a CDMA System

- Resources in a CDMA system
 - codes
 - transmitted power
 - processing gain
- Resource allocation should
 - Accommodate multiple types of traffic with different QoS requirements
 - Maximize system capacity
 - Improve system performance



Conventional Approach

- Implement resource allocation by assigning
 - power
 - processing gain
 - modulation schemes
 - diversity
- Limitations
 - Requires characterization of each traffic flow
 - No notion of user benefit



Utility-Based Resource Allocation

- Base station sells power and codes
- Users respond according to willingness to pay (Utility) (Utility)
- Objective: maximize total utility or revenue
- Accommodates various traffic flows by assigning different utility functions
- Potential simplification or elimination of explicit admission control policies

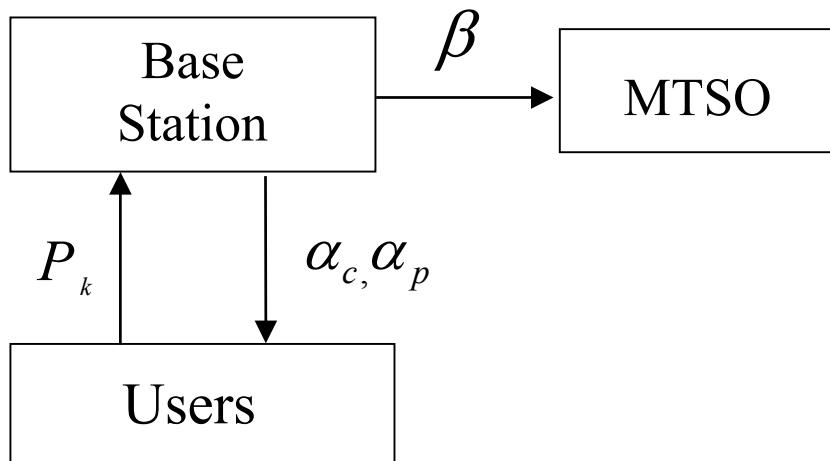


Model

- Isolated cell
- Forward link
- Orthogonal codes
- Voice traffic only



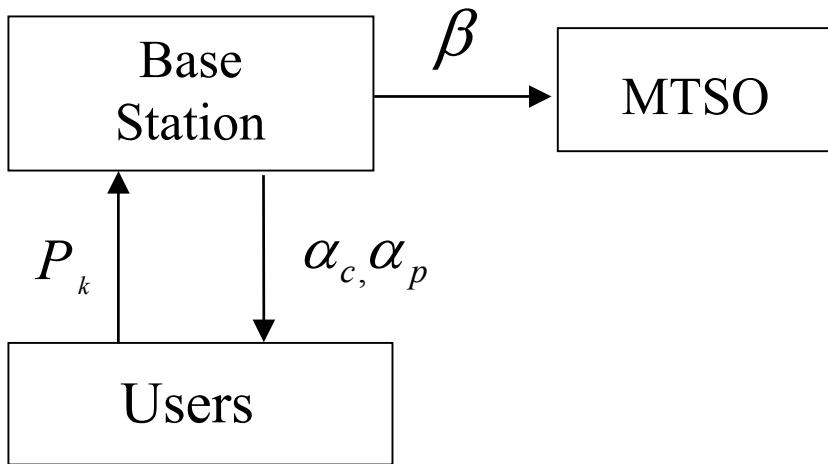
System Model



- Price per code, α_c
- Price per unit power, α_p



System Model

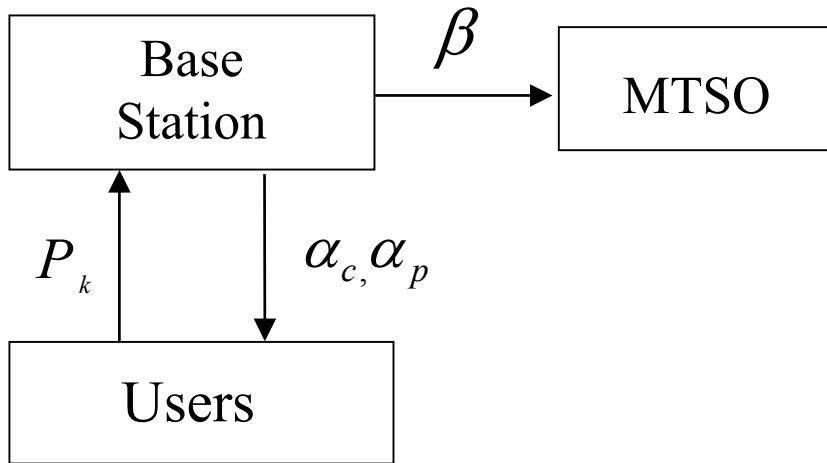


P_k :

- Forward link transmitted power from the BS to the user.
- Power required to satisfy target SINR.
- Uniquely determined by user location d_k distance from BS.
- $P_k = 0 \rightarrow$ user k inactive

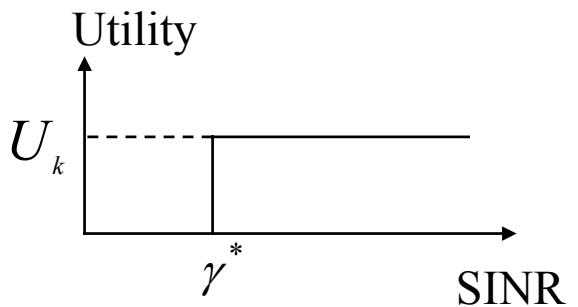


System Model



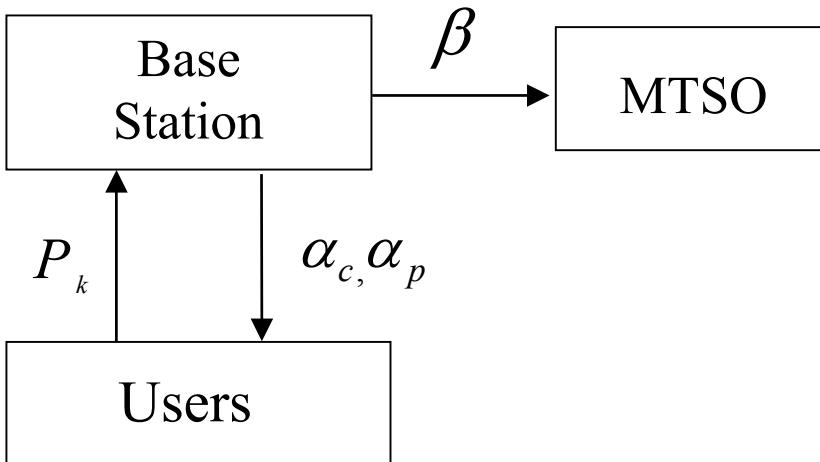
Utility as a function of QoS (in \$)

- Reflects user's willingness to pay.
- For voice traffic,
 $U(\text{SINR})$ is a step function.





System Model



β : Transfer payment to MTSO (in \$/unit power)

- Accounts for externality for interference to other cells
- Enforces a total power constraint



Optimization

- BS knows user utilities

→ set (α_c, α_p) to maximize

$$\text{Total utility } U(\alpha_c, \alpha_p) = \sum_S (U_k - \beta P_k)$$

where $S = \{ k : U_k \geq \alpha_c + \alpha_p P_k \}$ is the active user set

- BS does not know user utilities

→ set (α_c, α_p) to maximize

$$\text{Total revenue } R(\alpha_c, \alpha_p) = \sum_S (\alpha_c + \alpha_p P_k - \beta P_k)$$

- Code constraint: $|S| / M \leq 1$

M is the total # of codes available in the cell



Maximum Utility Solution

- Sort list of $(U_k - \beta P_k)$ 'sin decreasing order.
- $(U_k - \beta P_k) > 0$ for $k \leq N$
- Choose top $\min(N, M)$ users

$$\alpha_c = \min(0, U_M - \beta P_M)$$

$$\alpha_p = \beta$$



Large system Analysis

- $K = \# \text{ users per cell} \longrightarrow \infty$
- $M = \# \text{ orthogonal codes in a cell} \longrightarrow \infty$
- load $\rho = K / M = \text{constant} < \infty$
- Eliminates discontinuities in objective function for a finite-sized system
- $f_U = \text{p.d.f. of utility } U_k$
- $f_P = \text{p.d.f. of power } P_k$



Optimization

- Maximize total utility

$$U(\alpha_c, \alpha_p) = \iint_Q (u - \beta p) f_U(u) f_P(p) dQ$$

where $Q = \{(u, p) : u \geq \alpha_c + \alpha_p p\}$ is the active user set

- Maximize total revenue

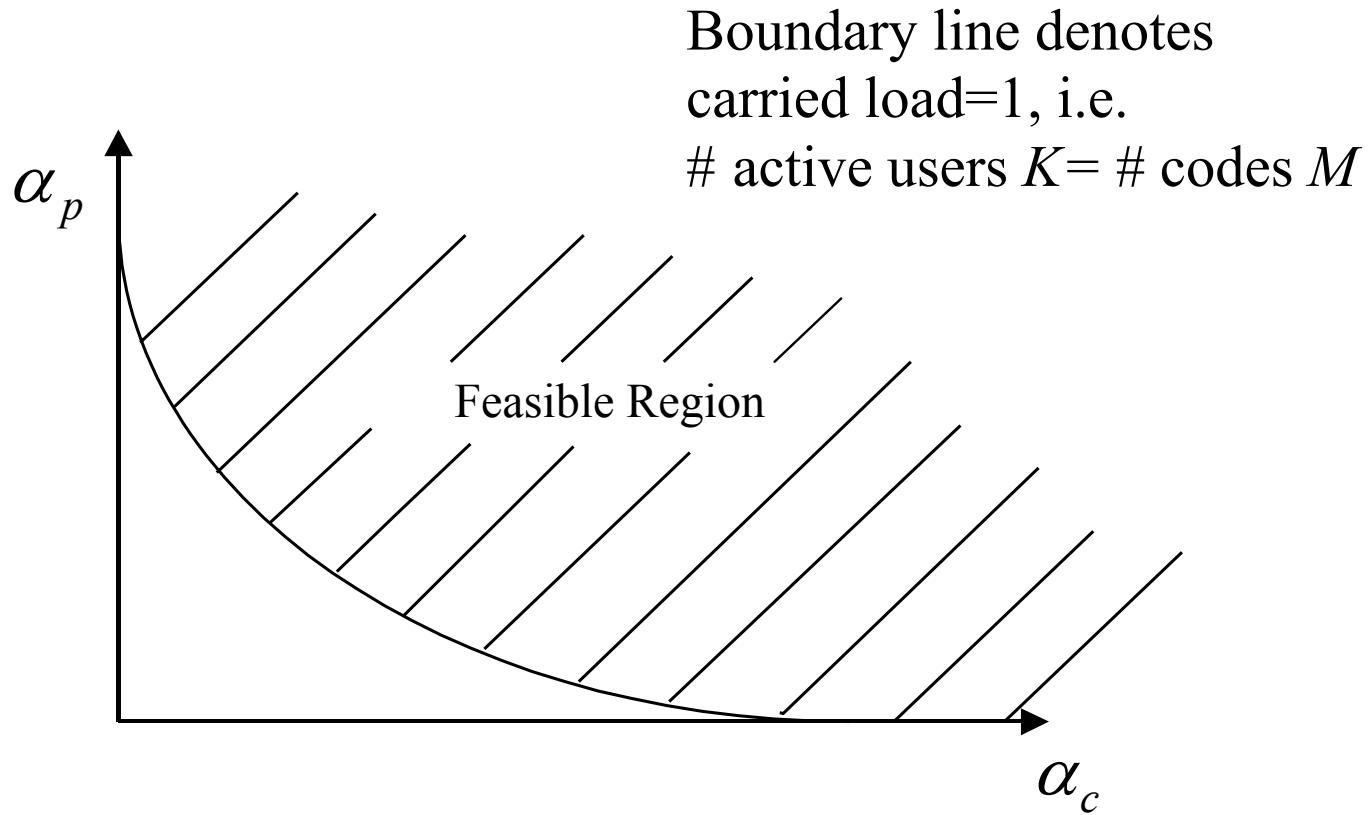
$$R(\alpha_c, \alpha_p) = \iint_Q [\alpha_c + (\alpha_p - \beta)p] f_U(u) f_P(p) dQ$$

- Feasibility constraint:

$$\iint_Q f_U(u) f_P(p) dQ \leq 1/\rho$$



Feasible Region





Maximize Utility

- BS knows $f_U(u), f_P(p)$.
- Solution

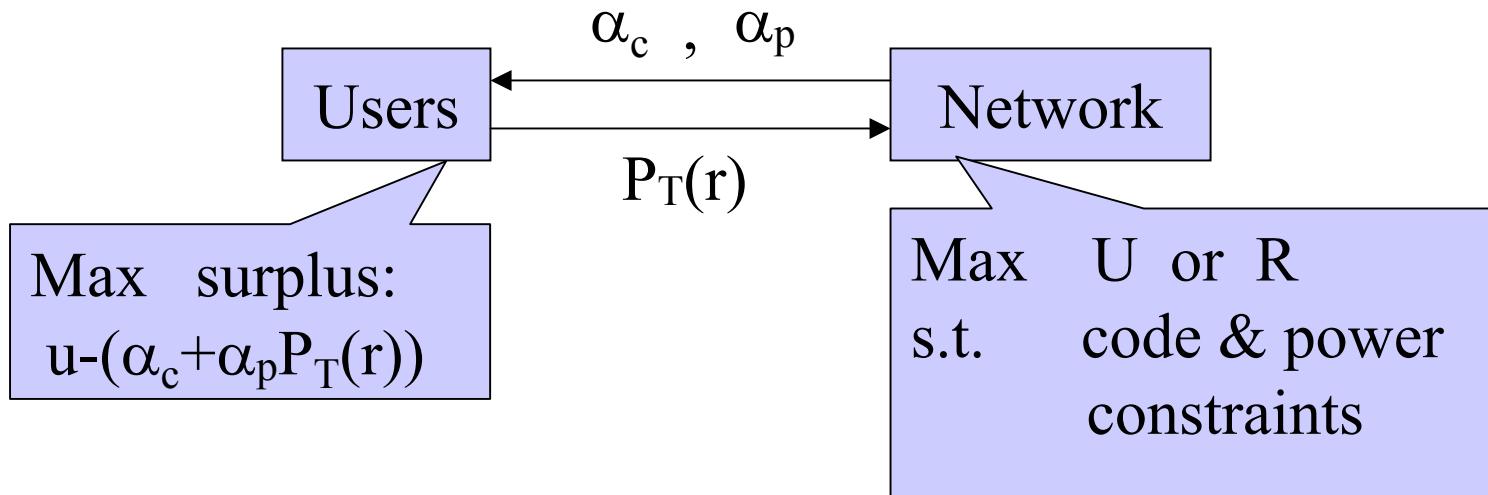
If $\rho \leq 1$, $\alpha_c = 0$

If $\rho > 1$, α_c is chosen such that

$$\int_0^\infty \int_{\alpha_c + \beta p}^\infty f_U(u) f_P(p) dudp = 1/\rho$$

$$\alpha_p = \beta$$

Pricing

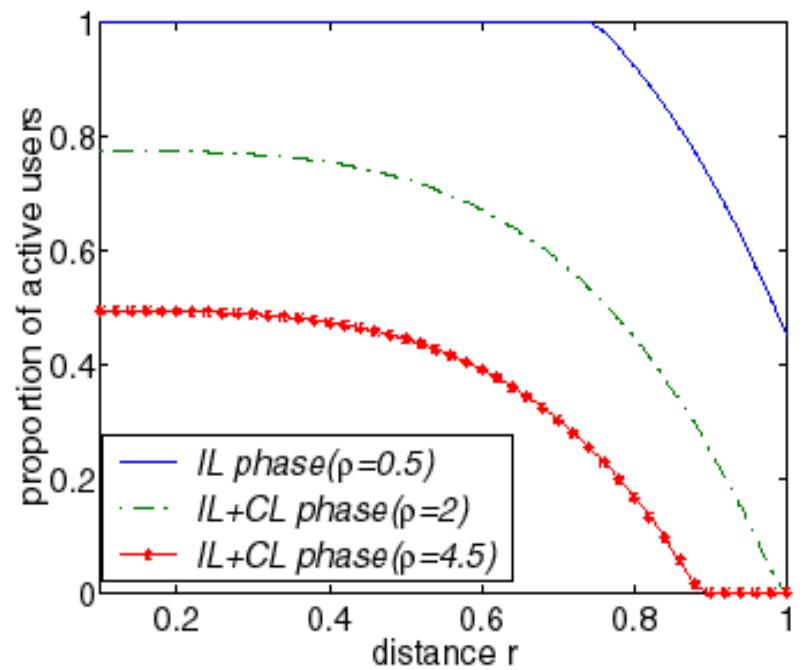
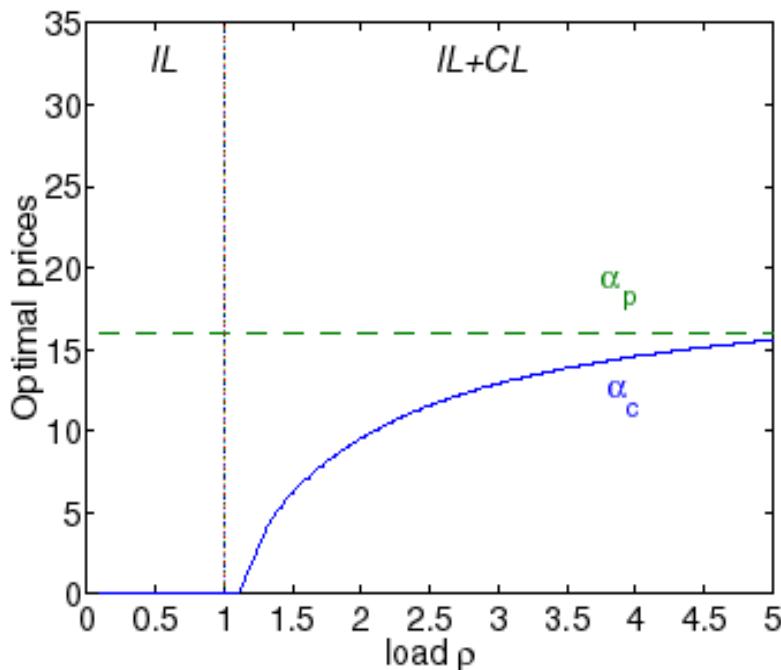


Cell Phases

- CL(code-limited):
 - code constraint is binding
- PL(power-limited):
 - power constraint is binding
- IL(interference-limited):
 - transfer price $\beta > 0$
- DL(demand-limited):
 - Neither CL, PL nor IL

Utility Maximization (1)

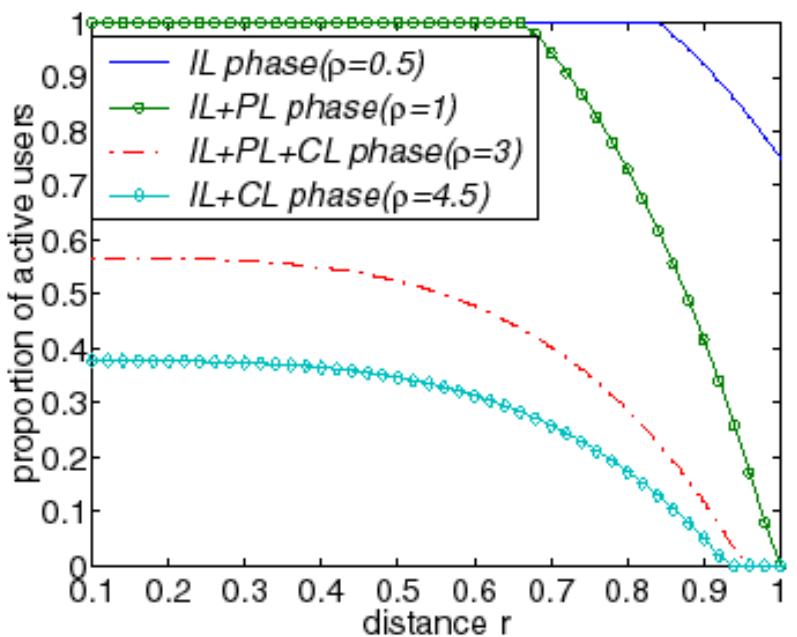
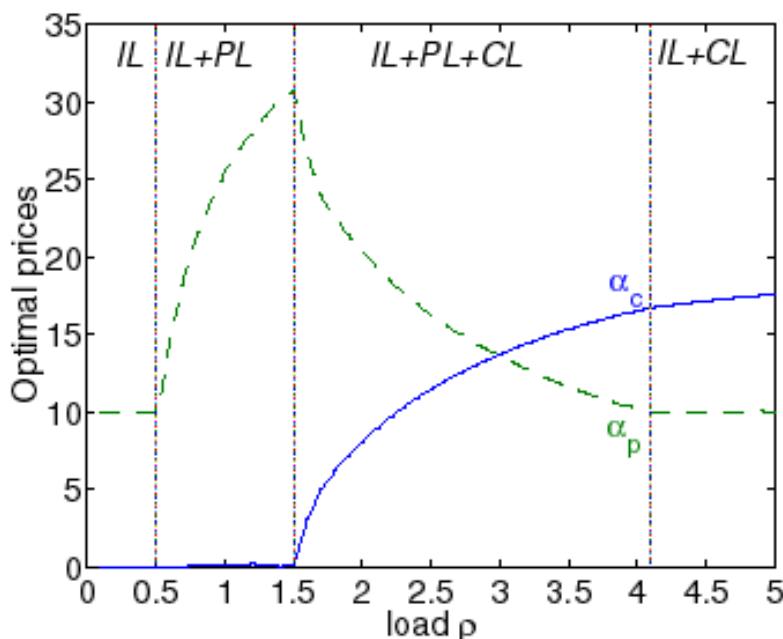
- Uniform utility distribution $PP=1000$ & $\beta=16$



Comments: $\alpha_c > 0$ iff the cell is CL
 $\alpha_p = \beta$ iff the cell is not PL

Utility Maximization (2)

- Uniform utility distribution $PP=500$ & $\beta=10$



Comments: $\alpha_p > \beta$ iff the cell is PL

$IL \rightarrow IL+PL \rightarrow IL+PL+CL \rightarrow IL+CL$

Shadow Cost

- Code constraint:

- $\iint_Q f_u f_r dudr \leq \frac{1}{\rho}$

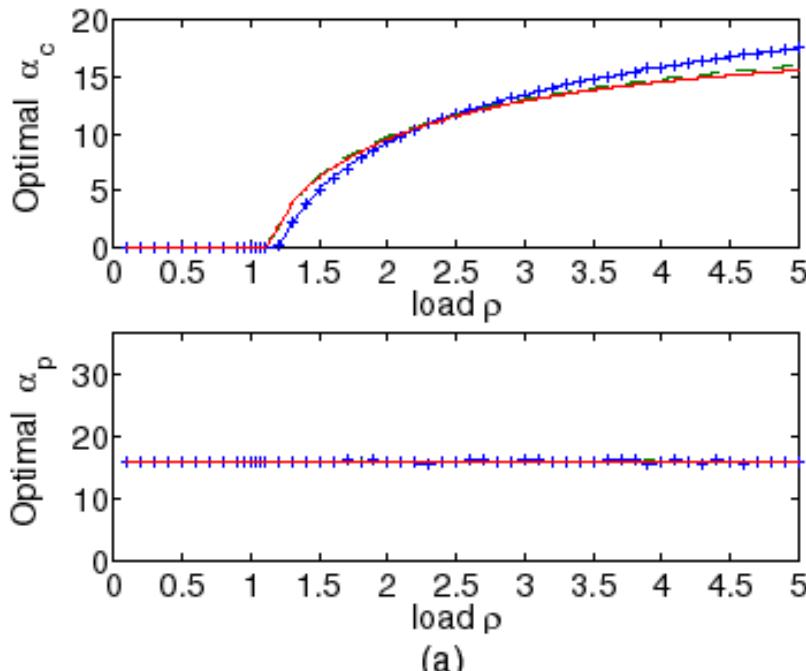
- α_c = shadow cost for code constraint

- Power constraint:

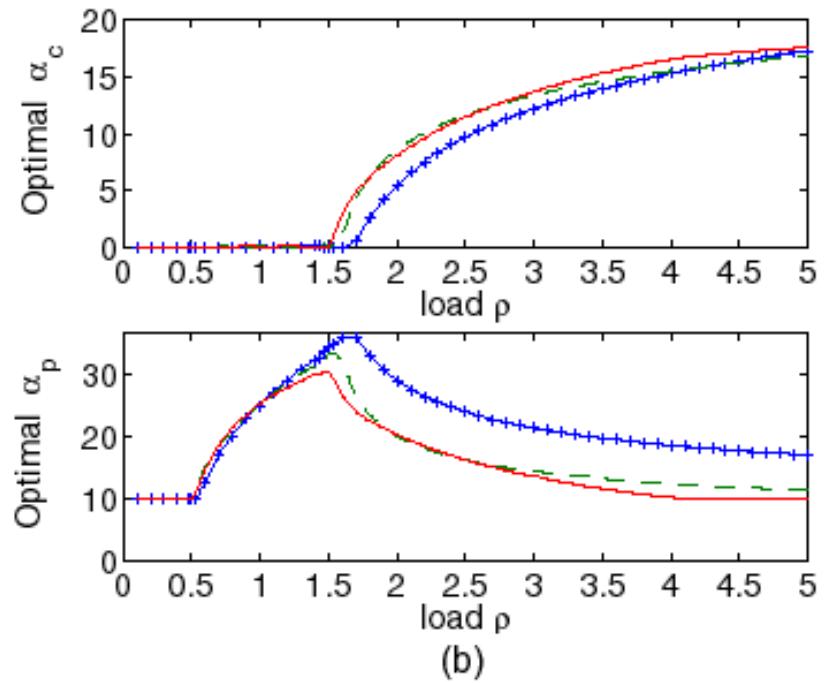
- $\iint_Q P_T(r) f_u f_r dudr \leq \frac{PP}{\rho}$

- $\alpha_p = \beta +$ shadow cost for power constraint

Utility Maximization (3)

(a) PP=1000 & $\beta=16$ 

(a)

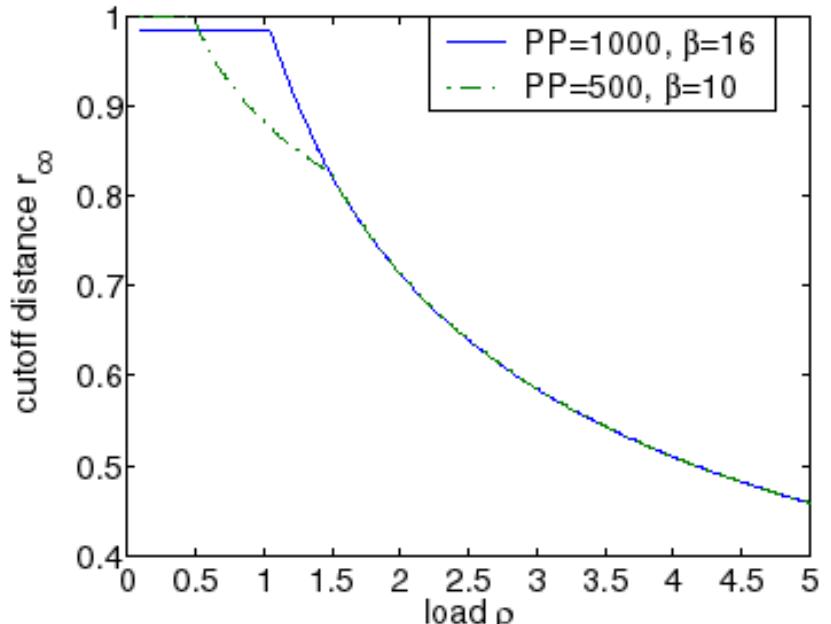
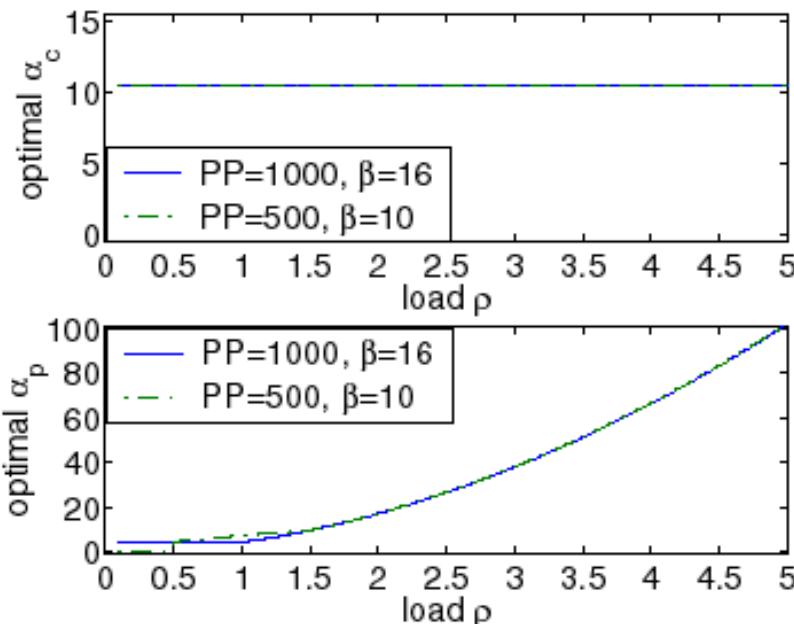
(b) PP=500 & $\beta=10$ 

(b)

‘—’ : uniform $\mu=15, \sigma=5.77$ ‘---’ : Gaussian $\mu=15, \sigma=5.77$ ‘+++’ : Gaussian $\mu=15, \sigma=10$

Utility Maximization (4)

- $\delta(u-u_0)$ utility distribution

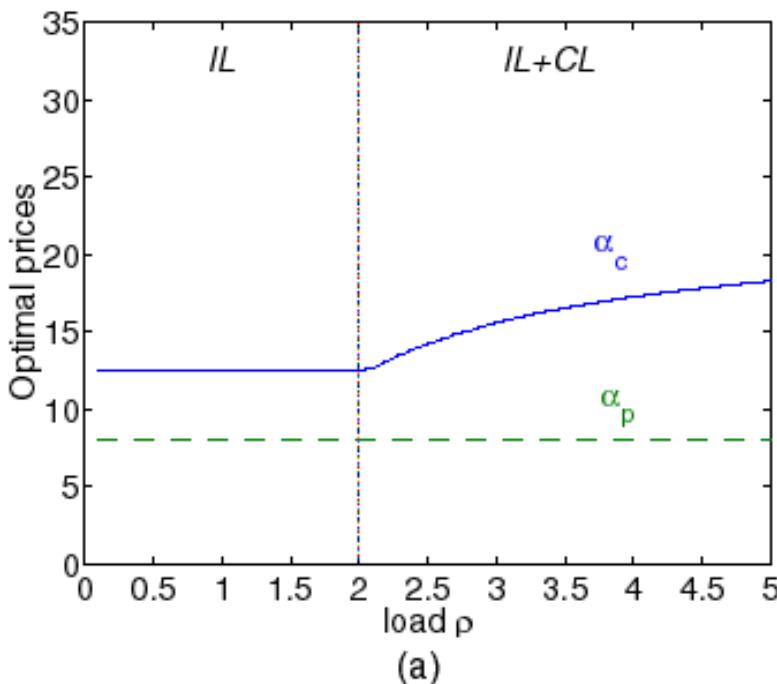


Comments: For every cutoff distance r_{co} , there are infinite number of optimal (α_c, α_p) pairs.

Revenue Maximization (1)

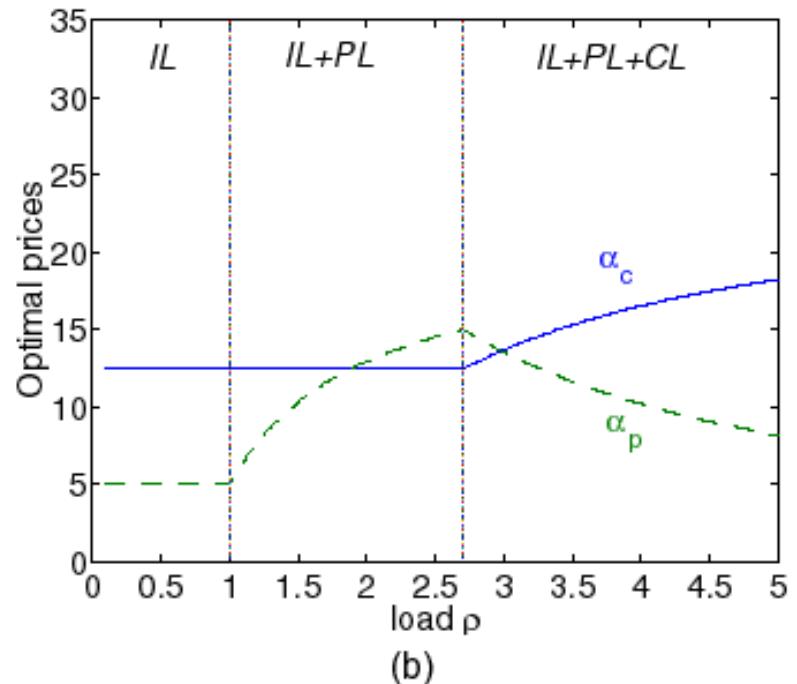
- Uniform utility distribution

(a) PP=1000 & $\beta=16$



(a)

(b) PP=500 & $\beta=10$



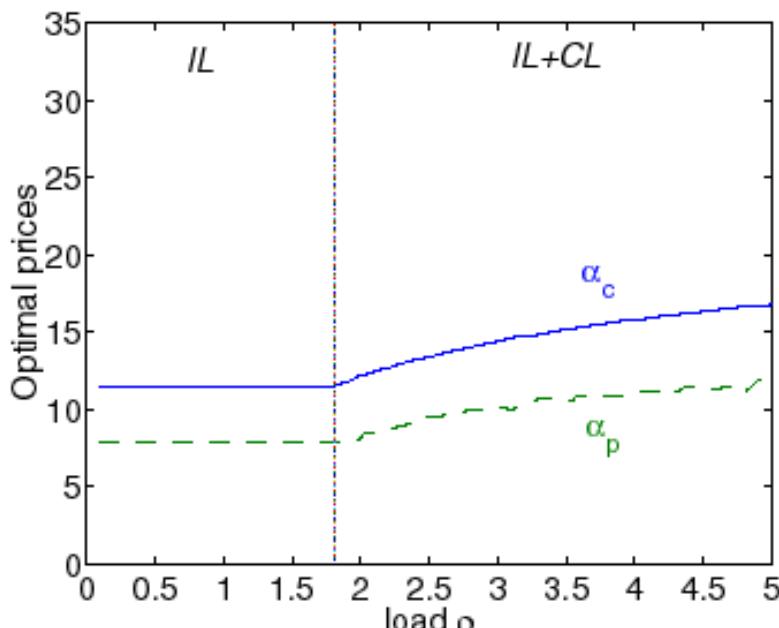
(b)

Comments: $\alpha_c > 0$ ($= u_2/2$) when the cell is not CL
 $\alpha_p > 0$ ($= \beta/2$) when the cell is not PL

Revenue Maximization (2)

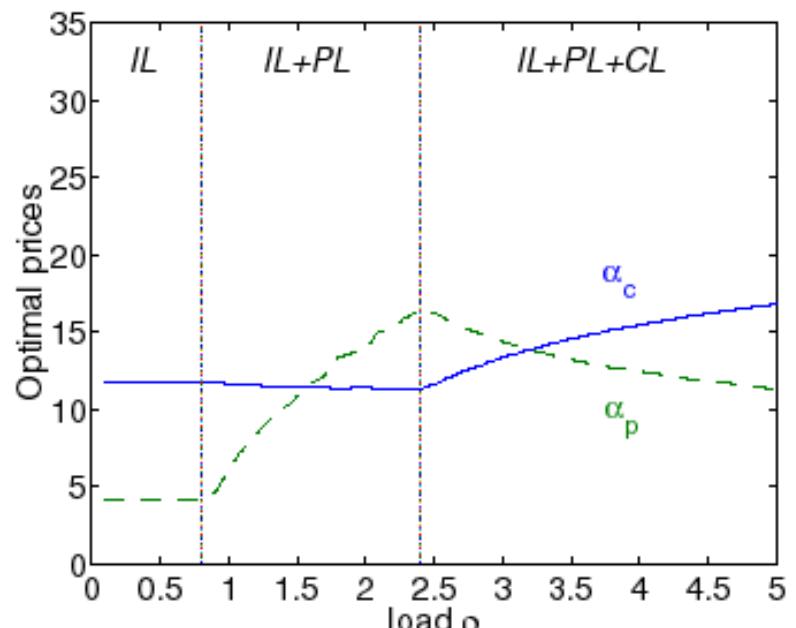
- Gaussian utility distribution

(a) PP=1000 & $\beta=16$



(a)

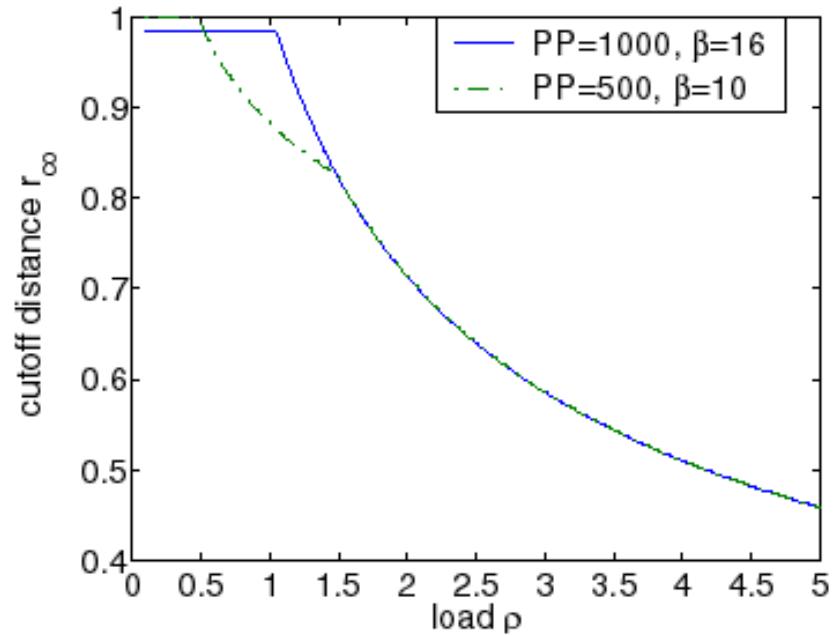
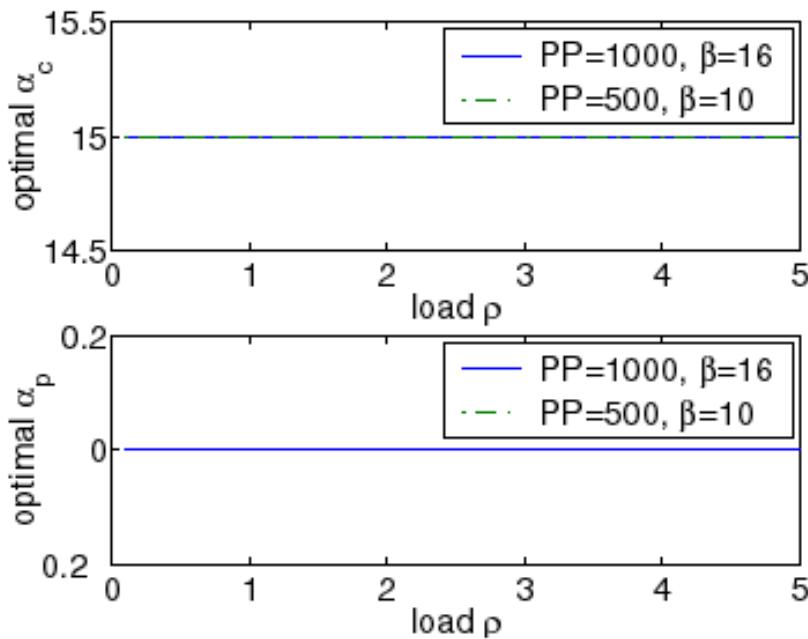
(b) PP=500 & $\beta=10$



(b)

Revenue Maximization (3)

- $\delta(u-u_0)$ utility distribution



Comments: $\alpha_c = u_0$ and $\alpha_p = 0$

Revenue max. is a special case of Utility max.

Conclusion

- Max U → prices set to shadow cost achieve optimality
- Max R → prices may be increased above shadow cost
- Next: 2 cells & multimedia